Tech Briefs

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INTRODUCTION

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NASA TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Situational Awareness From a Low-Cost Camera System

This technology can be used for 3D scene extraction and automatic targeting in security and vehicle-monitoring systems.

Dryden Flight Research Center, Edwards, California

A method gathers scene information from a low-cost camera system. Existing surveillance systems using sufficient cameras for continuous coverage of a large field necessarily generate enormous amounts of raw data. Digitizing and channeling that data to a central computer and processing it in real time is difficult when using low-cost, commercially available components. A newly developed system is located on a combined power and data wire to form a string-of-lights camera system. Each camera is accessible through this network interface using standard TCP/IP networking protocols.

The upper half of the figure depicts a **String-of-Lights Camera System** installed to observe multiple physical spaces with arbitrary overlapping views. The lower figure presents block diagram of major components within a single camera.

The cameras more closely resemble cellphone cameras than traditional security camera systems. Processing capabilities are built directly onto the camera backplane, which helps maintain a low cost.

The low power requirements of each camera allow the creation of a single imaging system comprising over 100 cameras. Each camera has built-in processing capabilities to detect events and cooperatively share this information with neighboring cameras. The location of the event is reported to the host computer in Cartesian coordinates computed from data correlation across multiple cameras. In this way, events in the field of view can present low-bandwidth information to the host rather than high-bandwidth bitmap data constantly being generated by the cameras. This approach offers greater flexibility than conventional systems, without compromising performance through using many small, low-cost cameras with overlapping fields of view. This means significant increased viewing without ignoring surveillance areas, which can occur when pan, tilt, and zoom cameras look away. Additionally, due to the sharing of a single cable for power and data, the installation costs are lower.

The technology is targeted toward 3D scene extraction and automatic target tracking for military and commercial applications. Security systems and environmental/vehicular monitoring systems are also potential applications.

This work was done by Lawrence C. Freudinger of Dryden Flight Research Center and David Ward and John Lesage of SemQuest, Inc. For more information, contact SemQuest, Inc. at (719) 447-8757. DRC-007-022

Data Acquisition System for Multi-Frequency Radar Flight Operations Preparation

John H. Glenn Research Center, Cleveland, Ohio

A three-channel data acquisition system was developed for the NASA Multi-Frequency Radar (MFR) system. The system is based on a commercial-off-the-shelf (COTS) industrial PC (personal computer) and two dual-channel 14-bit digital receiver cards. The decimated complex envelope representations of the three radar signals are passed to the host PC via the PCI bus, and then processed in parallel by multiple cores of the PC CPU (central processing unit). The innovation is this parallelization of the radar data processing using multiple cores of a standard COTS multi-core CPU.

The data processing portion of the data acquisition software was built using autonomous program modules or threads, which can run simultaneously on different cores. A master program module calculates the optimal number of processing threads, launches them, and continually supplies each with data.

The benefit of this new parallel software architecture is that COTS PCs can be used to implement increasingly complex processing algorithms on an increasing number of radar range gates and data rates. As new PCs become available with higher numbers of CPU cores, the software will automatically utilize the additional computational capacity.

This work was done by Jonathan Leachman of ProSensing, Inc. for Glenn Research Center.

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18465-1.

Mercury Toolset for Spatiotemporal Metadata

Goddard Space Flight Center, Greenbelt, Maryland

Mercury (http://mercury.ornl.gov) is a set of tools for federated harvesting, searching, and retrieving metadata, particularly spatiotemporal metadata. Version 3.0 of the Mercury toolset provides orders of magnitude improvements in search speed, support for additional metadata formats, integration with Google Maps for spatial queries, facetted type search, support for RSS (Really Simple Syndication) delivery of search results, and enhanced customization to meet the needs of the multiple projects that use Mercury. It provides a single portal to very quickly search for data and information contained in disparate data management systems, each of which may use different metadata formats. Mercury harvests metadata and key data from contributing project servers distributed around the world and builds a centralized index. The search interfaces then allow the users to perform a variety of fielded, spatial, and temporal searches across these metadata sources. This centralized repository of metadata with distributed data sources provides extremely fast search results to the user, while allowing data providers to advertise the availability of their data and maintain complete control and ownership of that data.

Mercury periodically (typically daily) harvests metadata sources through a collection of interfaces and re-indexes these metadata to provide extremely rapid search capabilities, even over collections with tens of millions of metadata records. A number of both graphical and application interfaces have been constructed within Mercury, to enable both human users and other computer programs to perform queries. Mercury was also designed to support multiple different projects, so that the particular fields that can be queried and used with search filters are easy to configure for each different project.

This work was done by Bruce E. Wilson, Giri Palanisamy, Ranjeet Devarakonda, B. Timothy Rhyne, and Chris Lindsley of UT-Battelle; and James Green of Information International Associates for Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15723-1

Social Tagging of Mission Data

NASA's Jet Propulsion Laboratory, Pasadena, California

Mars missions will generate a large amount of data in various forms, such as daily plans, images, and scientific information. Often, there is a semantic linkage between images that cannot be captured automatically. Software is needed that will provide a method for creating arbitrary tags for this mission data so that items with a similar tag can be related to each other. The tags should be visible and searchable for all users.

A new routine was written to offer a new and more flexible search option over previous applications. This software allows users of the MSLICE program to apply any number of arbitrary tags to a piece of mission data through a MSLICE search interface. The application of tags creates relationships between data that did not previously exist. These tags can be easily removed and changed, and contain enough flexibility to be specifically configured for any mission. This gives users the ability to quickly recall or draw attention to particular pieces of mission data, for example:

• Give a semantic and meaningful description to mission data; for example, tag all images with a rock in them with the tag "rock."
• Rapidly recall specific and useful pieces of data; for example, tag a plan as "driving template."
• Call specific data to a user's attention; for example, tag a plan as "for:User."

This software is part of the MSLICE release, which was written in Java. It will run on any current Windows, Macintosh, or Linux system.

This work was done by Jeffrey S. Norris, Michael N. Wallick, Joseph C. Joswig, Mark W. Powell, Recaredo J. Torres, David S. Mittman, Lucy Abramyan, Thomas M. Crockett, Khawaja S. Shams, and Jason M. Fox of Caltech; Guy Pyrzak of Ames Research Center; and Michael B. Vaughn of the University of Wisconsin-Madison for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-46827

Integrating Radar Image Data With Google Maps

NASA's Jet Propulsion Laboratory, Pasadena, California

A public Web site has been developed as a method for displaying the multitude of radar imagery collected by NASA's Airborne Synthetic Aperture Radar (AIRSAR) instrument during its 16-year mission. Utilizing NASA's internal AIRSAR site, the new Web site features more sophisticated visualization tools that enable the general public to have access to these images.

The site was originally maintained at NASA on six computers: one that held the Oracle database, two that took care of the software for the interactive map, and three that were for the Web site itself. Several tasks were involved in moving this complicated setup to just one computer.

First, the AIRSAR database was migrated from Oracle to MySQL. Then the back-end of the AIRSAR Web site was updated in order to access the MySQL database. To do this, a few of the scripts needed to be modified; specifically three Perl scripts that query that database. The database connections were then updated from Oracle to MySQL, numerous syntax errors were corrected, and a query was implemented that replaced one of the stored Oracle procedures. Lastly, the interactive map was designed, implemented, and tested so that users could easily browse and access the radar imagery through the Google Maps interface.

This work was done by Bruce D. Chapman of Caltech and Sarah Gibas of the University of California Irvine for NASA's Jet Propulsion Laboratory. For more information, see http://airsar.jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-46492.

Electronics/Computers

Demonstration of a Submillimeter-Wave HEMT Oscillator Module at 330 GHz

This low-mass, low-power module may be useful for hidden weapons detection and airport security.

NASA's Jet Propulsion Laboratory, Pasadena, California

In this work, radial transitions have been successfully mated with a HEMT-based MMIC (high-electron-mobility-transistor-based monolithic microwave integrated circuit) oscillator circuit. The chip has been assembled into a WR2.2 waveguide module for the basic implementation with radial E-plane probe transitions to convert the waveguide mode to the MMIC coplanar waveguide mode. The E-plane transitions have been directly integrated onto the InP substrate to couple the submillimeter-wave energy directly to the waveguides, thus avoiding wirebonds in the RF path. The oscillator demonstrates a measured 1.7 percent DC-RF efficiency at the module level.

The oscillator chip uses 35-nm-gate-length HEMT devices, which enable the high frequency of oscillation, creating the first demonstration of a packaged waveguide oscillator that operates over 300 GHz and is based on InP HEMT technology. The oscillator chip is extremely compact, with dimensions of only $1,085 \times 320$ µm^2 for a total die size of 0.35 mm^2. This fully integrated, waveguide oscillator module, with an output power of 0.27 mW at 330 GHz, can provide low-mass, low DC-power-consumption alternatives to existing local oscillator schemes, which require high DC power consumption and large mass.

This oscillator module can be easily integrated with mixers, multipliers, and amplifiers for building high-frequency transmit and receive systems at submillimeter wave frequencies. Because it requires only a DC bias to enable submillimeter wave output power, it is a simple and reliable technique for generating power at these frequencies. Future work will be directed to further improving the applicability of HEMT transistors to submillimeter wave and terahertz applications. Commercial applications include submillimeter-wave imaging systems for hidden weapons detection, airport security, homeland security, and portable low-mass, low-power imaging systems.

Flexible Peripheral Component Interconnect Input/Output Card

The card has applications in quality and testing systems for product design verification and manufacturing testing.

Lyndon B. Johnson Space Center, Houston, Texas

The Flexible Peripheral Component Interconnect (PCI) Input/Output (I/O) Card is an innovative circuit board that provides functionality to interface between a variety of devices. It supports user-defined interrupts for interface synchronization, tracks system faults and failures, and includes checksum and parity evaluation of interface data. The card supports up to 16 channels of high-speed, half-duplex, low-voltage digital signaling (LVDS) serial data, and can interface combinations of serial and parallel devices. Placement of a processor within the field programmable gate array (FPGA) controls an embedded application with links to host memory over its PCI bus. The FPGA also provides protocol stacking and quick digital signal processor (DSP) functions to improve host performance. Hardware timers, counters, state machines, and other glue logic support interface communications.

The Flexible PCI I/O Card provides an interface for a variety of dissimilar computer systems, featuring direct memory access functionality. The card has the following attributes:
- 8/16/32-bit, 33-MHz PCI r2.2 compliance,
- Configurable for universal 3.3V/5V interface slots,
- PCI interface based on PLX Technology's PCI9056 ASIC,
- General-use 512K×16 SDRAM memory,
- General-use 1M×16 Flash memory,
- FPGA with 3K to 56K logical cells with embedded 27K to 198K bits RAM,
- I/O interface: 32-channel LVDS differential transceivers configured in eight, 4-bit banks; signaling rates to 200 MHz per channel,
- Common SCSI-3, 68-pin interface connector.

The Flexible PCI I/O Card was integrated into the Shuttle Mission Simulator (SMS) as a more efficient means of interfacing between the Silicon Graphic Inc. (SGI) simulation host and the Simulator Interface Device (SID). The

FPGA was developed to memory map the SID I/O data stream. The card eliminated the previous protocol that required generation of command word and word count I/O data blocks, and added functionality much like direct memory access.

The card was integrated into the Shuttle Avionics Integration Laboratory (SAIL) as an improved interface to the Linux-based Hosting Interface Device (HID). This card allowed replacement of a serial port to parallel data handling, thereby decreasing general-purpose computer (GPC) load times by about 10 minutes.

Finally, the Flexible PCI card was integrated in the SMS, and ready for implementation in the SAIL and to the KSC Avionics Test Set (KATS) Lab, to interface a Windows XP host to a dual channel MIA (media interface adapter) data

bus device, providing a means of simulating solid-state mass memory units to load Shuttle general purpose computers (GPCs).

This hardware and firmware work was done by Kirk K. Bigelow and software work was done by Albert L. Jerry, Alisha G. Barcio, and Jon K. Cummings of United Space Alliance for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24615-1

Interface Supports Lightweight Subsystem Routing for Flight Applications

NASA's Jet Propulsion Laboratory, Pasadena, California

A wireless avionics interface exploits the constrained nature of data networks in flight systems to use a lightweight routing method. This simplified routing means that a processor is not required, and the logic can be implemented as an intellectual property (IP) core in a field-programmable gate array (FPGA). The FPGA can be shared with the flight subsystem application. In addition, the router is aware of redundant subsystems, and can be configured to provide hot standby support as part of the interface. This simplifies implementation of flight applications requiring hot standby support.

When a valid inbound packet is received from the network, the destination node address is inspected to determine whether the packet is to be processed by this node. Each node has routing tables for the next neighbor node to guide the packet to the destination node. If it is to be processed, the final packet destination is inspected to determine whether the packet is to be forwarded to another node, or routed locally. If the packet is local, it is sent to an Applications Data Interface (ADI), which is attached to a local flight application. Under this scheme, an interface can support many applications in a subsystem supporting a high level of

subsystem integration. If the packet is to be forwarded to another node, it is sent to the outbound packet router. The outbound packet router receives packets from an ADI or a packet to be forwarded. It then uses a lookup table to determine the next destination for the packet. Upon detecting a remote subsystem failure, the routing table can be updated to autonomously bypass the failed subsystem.

This work was done by James P. Lux, Gary L. Block, Mohammad Ahmad, William D. Whitaker, and James W. Dillon of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-46322

MMIC Amplifiers and Wafer Probes for 350 to 500 GHz

Amplifiers like these are needed for submillimeter-wavelength imagers and scientific instruments.

NASA's Jet Propulsion Laboratory, Pasadena, California

Several different experimental monolithic microwave integrated circuit (MMIC) amplifiers have been designed to operate in frequency bands ranging from 350 to 500 GHz and were undergoing fabrication at the time of reporting the information for this article. Probes for on-wafer measurement of electrical parameters [principally, the standard scattering parameters ("S" parameters)] of these amplifiers have been built and tested as essential components of systems to be used in quantifying the performances of the amplifiers. These accomplishments are intermediate products of a continuing effort to develop solid-state electronic amplifiers capable of producing gain at ever-higher

frequencies, now envisioned to range up to 800 GHz. Such amplifiers are needed for further development of compact, portable imaging systems and scientific instruments for a variety of potential applications that include detection of hidden weapons, measuring winds, and measuring atmospheric concentrations of certain molecular species.

Seven of the experimental MMIC amplifiers are single-stage amplifiers; two are three-stage amplifiers. Conceptually, each amplifier is built around an InP-based high-electron-mobility transistor (HEMT) having a gate length of 35 nm, which has been developed at Northrop Grumman Corporation. It was previously demonstrated that the particular

HEMT can be fabricated with a high degree of reproducibility, that its electrical characteristics are accurately represented by a device model needed to design an MMIC that incorporates it, and that an experimental single-stage MMIC built around it exhibits 5 dB of gain at 345 GHz.

The seven present single-stage amplifier designs were derived from that of the 345-GHz MMIC amplifier. They were designed by use of the aforementioned device model, with modified layouts chosen to satisfy requirements for both (1) compatibility with the HEMT manufacturer's fabrication rules and (2) matching impedances at the affected frequency bands in the 350-to-500 GHz range. The
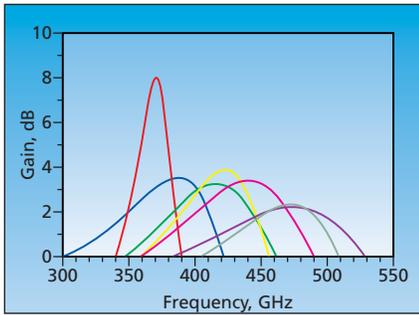
Figure 1. **Gains of Seven Single-Stage MMIC Amplifiers** built around advanced InP HEMTs were predicted in computational simulations.

Figure 2. **Wafer Probes** are mounted on the terminals of a network analyzer, with the probe tips in contact with a calibration substrate.

designs utilize several different matching-circuit topologies, some of which resemble topologies heretofore required for multi-stage amplifiers. Figure 1 shows the gains of the single-stage amplifiers as predicted by computational simulations.
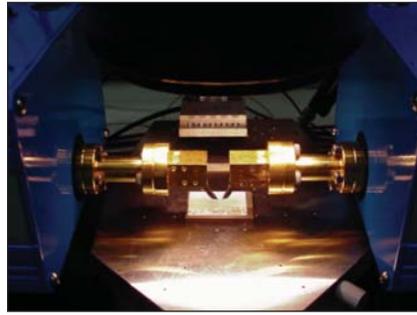
The two three-stage amplifiers were designed to operate at frequencies from 400 to 500 GHz, with peak gains in the approximate range of 11 to 13 dB.

The wafer probes were designed and built for use with a two-port swept-vector network analyzer that operates in the frequency range of 325 to 500 GHz. This network analyzer has been fully characterized for reproducibility and dynamic range. The probes include WR2.2 waveguides and waveguide-to-coaxial transitions developed at Cascade Microtech and Portland State University (see Figure 2). The insertion loss of the waveguide-to-coaxial transitions has been measured to be about 7 dB at 325 to 500 GHz.

Software

Public Risk Assessment Program

The Public Entry Risk Assessment (PERA) program addresses risk to the public from shuttle or other spacecraft re-entry trajectories. Managing public risk to acceptable levels is a major component of safe spacecraft operation. PERA is given scenario inputs of vehicle trajectory, probability of failure along that trajectory, the resulting debris characteristics, and field size and distribution, and returns risk metrics that quantify the individual and collective risk posed by that scenario. Due to the large volume of data required to perform such a risk analysis, PERA was designed to streamline the analysis process by using innovative mathematical analysis of the risk assessment equations. Real-time analysis in the event of a shuttle contingency operation, such as damage to the Orbiter, is possible because PERA allows for a change to the probability of failure models, therefore providing a much quicker estimation of public risk.

PERA also provides the ability to generate movie files showing how the entry risk changes as the entry develops. PERA was designed to streamline the computation of the enormous amounts of data needed for this type of risk assessment by using an average distribution of debris on the ground, rather than pinpointing the impact point of every piece of debris. This has reduced the amount of computational time significantly without reducing the accuracy of the results. PERA was written in MATLAB; a compiled version can run from a DOS or UNIX prompt.

This program was written by Gavin Mendeck of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24166-1

Particle Swarm Optimization Toolbox

The Particle Swarm Optimization Toolbox is a library of evolutionary optimization tools developed in the MATLAB environment. The algorithms contained in the library include a genetic algorithm (GA), a single-objective particle swarm optimizer (SOPSO), and a multi-objective particle swarm optimizer (MOPSO). Development focused on both the SOPSO and MOPSO. A GA was included mainly for comparison purposes, and the particle swarm optimizers appeared to perform better for a wide variety of optimization problems. All algorithms are capable of performing unconstrained and constrained optimization. The particle swarm optimizers are capable of performing single and multi-objective optimization. The SOPSO and MOPSO algorithms are based on swarming theory and bird-flocking patterns to search the trade space for the optimal solution or optimal trade in competing objectives. The MOPSO generates Pareto fronts for objectives that are in competition.

A GA, based on Darwin evolutionary theory, is also included in the library. The GA consists of individuals that form a population in the design space. The population mates to form offspring at new locations in the design space. These offspring contain traits from both of the parents. The algorithm is based on this combination of traits from parents to hopefully provide an improved solution than either of the original parents. As the algorithm progresses, individuals that hold these optimal traits will emerge as the optimal solutions.

Due to the generic design of all optimization algorithms, each algorithm interfaces with a user-supplied objective function. This function serves as a "black-box" to the optimizers in which the only purpose of this function is to evaluate solutions provided by the optimizers. Hence, the user-supplied function can be numerical simulations, analytical functions, etc., since the specific detail of this function is of no concern to the optimizer. These algorithms were originally developed to support entry trajectory and guidance design for the Mars Science Laboratory mission but may be applied to any optimization problem.

The MSL simulations reside on a computational network of development computers and two clusters at NASA Langley. The MSL can take advantage of the parallel nature of these population-based algorithms with the optimization algorithms running with the Mars entry simulations on the Langley clusters via the user-supplied interface. Other problems for which this software might be used do not necessarily require use of the Langley clusters. The group in which this innovation was developed uses the algorithms for MSL, but due to its generic nature, other uses can include Crew Exploration Vehicle ascent, entry, mission design, or any other project that can use this type of toolset.

This program was written by Michael J. Grant for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24261-1.

Telescience Support Center Data System Software

The Telescience Support Center (TSC) team has developed a database-driven, increment-specific Data Requirement Document (DRD) generation tool that automates much of the work required for generating and formatting the DRD. It creates a database to load the required changes to configure the TSC data system, thus eliminating a substantial amount of labor in database entry and formatting.

The TSC database contains the TSC systems configuration, along with the experimental data, in which human physiological data must be de-commutated in real time. The data for each experiment also must be cataloged and archived for future retrieval. TSC software provides tools and resources for ground operation and data distribution to remote users consisting of PIs (principal investigators), bio-medical engineers, scientists, engineers, payload specialists, and computer scientists. Operations support is provided for computer systems access, detailed networking, and mathematical and computational problems of the International Space Station telemetry data.

User training is provided for on-site staff and biomedical researchers and other remote personnel in the usage of the space-bound services via the Internet, which enables significant resource savings for the physical facility along with the time savings versus traveling to NASA sites. The software used in support of the TSC could easily be adapted to other Control Center applications. This would include not only other NASA payload monitoring facilities, but also other types

of control activities, such as monitoring and control of the electric grid, chemical, or nuclear plant processes, air traffic control, and the like.

This program was written by Hasan Rahman of Lockheed Martin for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24337-1

◉ Update on PISCES

An updated version of the Platform Independent Software Components for the Exploration of Space (PISCES) software library is available. A previous version was reported in "Library for Developing Spacecraft-Mission-Planning Software" (MSC-22983), *NASA Tech Briefs*, Vol. 25, No. 7 (July 2001), page 52. To recapitulate: This software provides for Web-based, collaborative development of computer programs for planning trajectories and trajectory-related aspects of spacecraft-mission design. The library was built using state-of-the-art object-oriented concepts and software-development methodologies. The components of PISCES include Java-language application programs arranged in a hierarchy of classes that facilitates the reuse of the components.

As its full name suggests, the PISCES library affords platform-independence: The Java language makes it possible to use the classes and application programs with a Java virtual machine, which is available in most Web-browser programs. Another advantage is expandability: Object orientation facilitates expansion of the library through creation of a new class. Improvements in the library since the previous version include development of orbital-maneuver-planning and rendezvous-launch-window application programs, enhancement of capabilities for propagation of orbits, and development of a "desktop" user interface.

This program was written by Don Pearson, Dustin Hamm, Brian Kubena, and Jonathan K. Weaver of Johnson Space Center. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809. MSC-23633-1

◉ Ground and Space Radar Volume Matching and Comparison Software

This software enables easy comparison of ground- and space-based radar observations. The software was initially designed to compare ground radar reflec-

tivity from operational, ground based S- and C-band meteorological radars with comparable measurements from the Tropical Rainfall Measuring Mission (TRMM) satellite's Precipitation Radar (PR) instrument. The software is also applicable to other ground-based and space-based radars. The ground and space radar volume matching and comparison software was developed in response to requirements defined by the Ground Validation System (GVS) of Goddard's Global Precipitation Mission (GPM) project.

This software innovation is specifically concerned with simplifying the comparison of ground- and space-based radar measurements for the purpose of GPM algorithm and data product validation. This software is unique in that it provides an operational environment to routinely create comparison products, and uses a direct geometric approach to derive common volumes of space- and ground-based radar data. In this approach, spatially coincident volumes are defined by the intersection of individual space-based Precipitation Radar rays with the each of the conical elevation sweeps of the ground radar. Thus, the resampled volume elements of the space and ground radar reflectivity can be directly compared to one another.

This work was done by Kenneth Morris and Mathew Schwaller of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). Additional information can also be found on the GPM GVS web site: http://gpm.gsfc.nasa.gov/groundvalidation.html. GSC-15738-1

◈ Web-Based Interface for Command and Control of Network Sensors

This software allows for the visualization and control of a network of sensors through a Web browser interface. It is currently being deployed for a network of sensors monitoring Mt. Saint Helen's volcano; however, this innovation is generic enough that it can be deployed for any type of sensor Web. From this interface, the user is able to fully control and monitor the sensor Web. This includes, but is not limited to, sending "test" commands to individual sensors in the network, monitoring for real-world events, and reacting to those events.

This work was done by Michael N. Wallick, Joshua R. Doubleday, and Khawaja S. Shams of Caltech for NASA's Jet Propulsion

Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47110.

◉ Orbit Determination Toolbox

The Orbit Determination Toolbox is an orbit determination (OD) analysis tool based on MATLAB and Java that provides a flexible way to do early mission analysis. The toolbox is primarily intended for advanced mission analysis such as might be performed in concept exploration, proposal, early design phase, or rapid design center environments. The emphasis is on flexibility, but it has enough fidelity to produce credible results. Insight into all flight dynamics source code is provided.

MATLAB is the primary user interface and is used for piecing together measurement and dynamic models. The Java Astrodynamics Toolbox is used as an engine for things that might be slow or inefficient in MATLAB, such as high-fidelity trajectory propagation, lunar and planetary ephemeris look-ups, precession, nutation, polar motion calculations, ephemeris file parsing, and the like. The primary analysis functions are sequential filter/smoother and batch least-squares commands that incorporate Monte-Carlo data simulation, linear covariance analysis, measurement processing, and plotting capabilities at the generic level.

These functions have a user interface that is based on that of the MATLAB ODE suite. To perform a specific analysis, users write MATLAB functions that implement truth and design system models. The user provides his or her models as inputs to the filter commands. The software provides a capability to publish and subscribe to a software bus that is compliant with the NASA Goddard Mission Services Evolution Center (GMSEC) standards, to exchange data with other flight dynamics tools to simplify the flight dynamics design cycle. Using the publish and subscribe approach allows for analysts in a rapid design center environment to seamlessly incorporate changes in spacecraft and mission design into navigation analysis and vice versa.

This work was done by James R. Carpenter and Kevin Berry of Goddard Space Flight Center and Kate Gregory, Keith Speckman, Sun Hur-Diaz, Derek Surka, and Dave Gaylor of Emergent Space Technologies, Inc. For

Distributed Observer Network

The Distributed Observer network (DON) is a NASA-collaborative environment that leverages game technology to bring three-dimensional simulations to conventional desktop and laptop computers in order to allow teams of engineers working on design and operations, either individually or in groups, to view and collaborate on 3D representations of data generated by authoritative tools such as Delmia Envision, Pro/Engineer, or Maya. The DON takes models and telemetry from these sources and, using commercial game engine technology, displays the simulation results in a 3D visual environment.

DON has been designed to enhance accessibility and user ability to observe and analyze visual simulations in real time. A variety of NASA mission segment simulations [Synergistic Engineering Environment (SEE) data, NASA Enterprise Visualization Analysis (NEVA) ground processing simulations, the DSS simulation for lunar operations, and the Johnson Space Center (JSC) TRICK tool for guidance, navigation, and control analysis] were experimented with. Desired functionalities, [i.e. Tivo-like functions, the capability to communicate textually or via Voice-over-Internet Protocol (VoIP)

among team members, and the ability to write and save notes to be accessed later] were targeted. The resulting DON application was slated for early 2008 release to support simulation use for the Constellation Program and its teams.

Those using the DON connect through a client that runs on their PC or Mac. This enables them to observe and analyze the simulation data as their schedule allows, and to review it as frequently as desired. DON team members can move freely within the virtual world. Preset camera points can be established, enabling team members to jump to specific views. This improves opportunities for shared analysis of options, design reviews, tests, operations, training, and evaluations, and improves prospects for verification of requirements, issues, and approaches among dispersed teams.

Computer-Automated Evolution of Spacecraft X-Band Antennas

A document discusses the use of computer-aided evolution in arriving at a design for X-band communication antennas for NASA's three Space Technology 5 (ST5) satellites, which were launched on March 22, 2006. Two evolutionary algorithms, incorporating different representations of the antenna design and different fitness functions, were used to automatically design and optimize an X-band antenna design. A set of antenna designs satisfying initial ST5 mission requirements was evolved by use these algorithms.

The two best antennas — one from each evolutionary algorithm — were built. During flight-qualification testing of these antennas, the mission requirements were changed. After minimal changes in the evolutionary algorithms — mostly in the fitness functions — new antenna designs satisfying the changed mission requirements were evolved and within one month of this change, two new antennas were designed and prototypes of the antennas were built and tested. One of these newly evolved antennas was approved for deployment on the ST5 mission, and flight-qualified versions of this design were built and installed on the spacecraft. At the time of writing the document, these antennas were the first computer-evolved hardware in outer space.

Manufacturing & Prototyping

Practical Loop-Shaping Design of Feedback Control Systems

Actuator rates are incorporated into a design from the start.

John H. Glenn Research Center, Cleveland, Ohio

An improved methodology for designing feedback control systems has been developed based on systematically shaping the loop gain of the system to meet performance requirements such as stability margins, disturbance attenuation, and transient response, while taking into account the actuation system limitations such as actuation rates and range. Loop-shaping for controls design is not new, but past techniques do not directly address how to systematically design the controller to maximize its performance. As a result, classical feedback control systems are designed predominantly using *ad hoc* control design approaches such as proportional integral derivative (PID), normally satisfied when a workable solution is achieved, without a good understanding of how to maximize the effectiveness of the control design in terms of competing performance requirements, in relation to the limitations of the plant design.

The conception of this improved methodology was motivated by challenges in designing control systems of the types needed for supersonic propulsion. But the methodology is generally applicable to any classical control-system design where the transfer function of the plant is known or can be evaluated. In the case of a supersonic aerospace vehicle, a major challenge is to de-

sign the system to attenuate anticipated external and internal disturbances, using such actuators as fuel injectors and valves, bypass doors, and ramps, all of which are subject to limitations in actuator response, rates, and ranges. Also, for supersonic vehicles, with long slim type of structures, coupling between the engine and the structural dynamics can produce undesirable effects that could adversely affect vehicle stability and ride quality.

In order to design distributed controls that can suppress these potential adverse effects, within the full capabilities of the actuation system, it is important to employ a systematic control design methodology such as this that can maximize the effectiveness of the control design in a methodical and quantifiable way.

The emphasis is in generating simple but rather powerful design techniques that will allow even designers with a layman's knowledge in controls to develop effective feedback control designs. Unlike conventional *ad hoc* methodologies of feedback control design, in this approach actuator rates are incorporated into the design right from the start: The relation between actuator speeds and the desired control bandwidth of the system is established explicitly. The technique developed is demonstrated via de-

sign examples in a step-by-step tutorial way. Given the actuation system rates and range limits together with design specifications in terms of stability margins, disturbance rejection, and transient response, the procedure involves designing the feedback loop gain to meet the requirements and maximizing the control system effectiveness, without exceeding the actuation system limits and saturating the controller. Then knowing the plant transfer function, the procedure involves designing the controller so that the controller transfer function together with the plant transfer function equate to the designed loop gain. The technique also shows what the limitations of the controller design are and how to trade competing design requirements such as stability margins and disturbance rejection. Finally, the technique is contrasted against other more familiar control design techniques, like PID control, to show its advantages.

Fully Printed High-Frequency Phased-Array Antenna on Flexible Substrate

This flexible design enables applications in high-frequency RFID sensors, smart cards, electronic paper, and flat-screen displays.

John H .Glenn Research Center, Cleveland, Ohio

To address the issues of flexible electronics needed for surface-to-surface, surface-to-orbit, and back-to-Earth communications necessary for manned exploration of the Moon, Mars, and beyond, a room-temperature printing process has been developed to create ac-

tive, phased-array antennas (PAAs) on a flexible Kapton substrate.

Field effect transistors (FETs) based on carbon nanotubes (CNTs), with many unique physical properties, were successfully proven feasible for phased-array antenna systems. The carrier mo-

bility of an individual CNT is estimated to be at least 100,000 $cm^2/V\cdot s$. The CNT network in solution has carrier mobility as high as 46,770 $cm^2/V\cdot s$, and has a large current-density carrying capacity of $\approx$ 1,000 mA/cm^2, which corresponds to a high carrying power of over 2,000

mW/cm^2. Such high carrier mobility, and large current carrying capacity, allows the achievement of high-speed (>100 GHz), high-power, flexible electronic circuits that can be monolithically integrated on NASA's active phased-array antennas for various applications, such as pressurized rovers, pressurized habitats, and spacesuits, as well as for locating beacon towers for lunar surface navigation, which will likely be performed at S-band and attached to a mobile astronaut.

A fully printed 2-bit 2-element phased-array antenna (PAA) working at 5.6 GHz, incorporating the CNT FETs as phase shifters, is demonstrated. The PAA is printed out at room temperature on 100-μm thick Kapton substrate. Four CNT FETs are printed together with microstrip time delay lines to function as a 2-bit phase shifter. The FET switch exhibits a switching speed of 0.2 ns, and works well for a 5.6-GHz RF signal. The operating frequency is measured to be 5.6 GHz, versus the state-of-the-art flexible FET operating frequency of 52 MHz. The source-drain current density is measured to be over 1,000 mA/cm^2, while the conventional organic FETs, and single carbon nanotube-based FETs, are typically in the μA to mA/cm^2 range. The switching voltage used is 1.8 V, while the state-of-the-art flexible FET has a gate voltage around 50 V. The gate voltage can effectively control the source-drain current with an ON-OFF ratio of over 1,000 obtained at a low V_{ds} bias of 1.8 V. The azimuth steering angles of PAA are measured at 0°, –14.5°, –30°, and 48.6°. The measured far-field patterns agree well with simulation results. The efficiency of the 2-bit 2-element PAA is measured to be 39 percent, including the loss of transmission line, FET switch, and coupling loss of RF probes. With further optimization, the efficiency is expected to be around 50–60 percent.

This work was done by Yihong Chen of Omega Optics, Inc. and Xuejun Lu of UMass Lowell for Glenn Research Center. Further information is contained in a TSP (see page 1).

Formula for the Removal and Remediation of Polychlorinated Biphenyls in Painted Structures

John F. Kennedy Space Center, Florida

An activated metal treatment system (AMTS) removes and destroys polychlorinated biphenyls (PCBs) found in painted structures or within the binding or caulking material on structures. It may be applied using a "paint-on and wipe-off" process that leaves the structure PCB-free and virtually unaltered in physical form. AMTS is used in conjunction with a solvent solution capable of donating hydrogen atoms. AMTS as a treatment technology has two functions: first, to extract PCBs from the material, and second, to degrade the extracted PCBs.

The process for removing PCBs from structures is accomplished as an independent step to the degradation process. The goal is to extract the PCBs out of the paint, without destroying the paint, and to partition the PCBs into an environmentally friendly solvent. The research to date indicates this can be accomplished within the first 24 hours of AMTS contact with the paint. PCBs are extremely hydrophobic and prefer to be in the AMTS over the hardened paint or binder material. The solvent selected must be used to open, but not to destroy, the paint's polymeric lattice structure, allowing pathways for PCB movement out of the paint and into the solvent. A number of solvent systems were tested and are available for use within the AMTS. The second process of the AMTS is the degradation or dehalogenation of the PCBs. The solvent selection for this process is limited to solvents that are capable of donating a hydrogen atom to the PCB structure.

Additional AMTS formulation properties that must be addressed for each site-specific application include viscosity and stability. The AMTS must be thick enough to remain where it is applied. Several thickening agents have been tested. Adding a stabilizing agent ensures that the AMTS will not evaporate and leave unprotected, activated metal exposed. During AMTS formulation testing, a number of reagents were evaluated to ensure the rate of dehalogenation was not inhibited by its addition to the system.

This work was done by Jacqueline Quinn and Kathleen Loftin of Kennedy Space Center and Cherie Geiger and Christian Clausen of Scientific Specialists Inc. For further information, contact the Kennedy Innovative Partnerships Program Office at (321) 867-5033. KSC-12878

Integrated Solar Concentrator and Shielded Radiator

Lyndon B. Johnson Space Center, Houston, Texas

A shielded radiator is integrated within a solar concentrator for applications that require protection from high ambient temperatures with little convective heat transfer. This innovation uses a reflective surface to deflect ambient thermal radiation, shielding the radiator. The interior of the shield is also reflective to provide a view factor to deep space. A key feature of the shield is the parabolic shape that focuses incoming solar radiation to a line above the radiator along the length of the trough. This keeps the solar energy from adding to the radiator load. By placing solar cells along this focal line, the concentration of solar energy reduces the number and mass of required cells.

By shielding the radiator, the effective reject temperature is much lower, allowing lower radiator temperatures. This is particularly important for lower-temperature processes, like habitat heat rejection and fuel cell operations where a high radiator temperature is not feasible. Adding the solar cells in the focal line uses the concentrating effect of the shield to advantage to accomplish two processes with a single device. This shield can be a deployable, lightweight Mylar structure for compact transport.

This work was done by David Larry Clark of Lockheed Martin Space Systems for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809. MSC-24447-1

Water Membrane Evaporator

Lyndon B. Johnson Space Center, Houston, Texas

A water membrane evaporator (WME) has been conceived and tested as an alternative to the contamination-sensitive and corrosion-prone evaporators currently used for dissipating heat from space vehicles. The WME consists mainly of the following components:
• An outer stainless-steel screen that provides structural support for the components mentioned next;
• Inside and in contact with the stainless-steel screen, a hydrophobic membrane that is permeable to water vapor;
• Inside and in contact with the hydrophobic membrane, a hydrophilic membrane that transports the liquid feedwater to the inner surface of the hydrophobic membrane;

- Inside and in contact with the hydrophilic membrane, an annular array of tubes through which flows the spacecraft coolant carrying the heat to be dissipated; and
- An inner exclusion tube that limits the volume of feedwater in the WME.

In operation, a pressurized feedwater reservoir is connected to the volume between the exclusion tube and the coolant tubes. Feedwater fills the volume, saturates the hydrophilic membrane, and is retained by the hydrophobic membrane. The outside of the WME is exposed to space vacuum. Heat from the spacecraft coolant is conducted through the tube walls and the water-saturated hydrophilic membrane to the liquid/vapor interface at the hydrophobic membrane, causing water to evaporate to space. Makeup water flows into the hydrophilic membrane through gaps between the coolant tubes.

Materials

Modeling of Failure for Analysis of Triaxial Braided Carbon Fiber Composites

Better understanding of triaxial braided composites will lead to improved aerospace and automotive structures.

John H. Glenn Research Center, Cleveland, Ohio

In the development of advanced aircraft-engine fan cases and containment systems, composite materials are beginning to be used due to their low weight and high strength. The design of these structures must include the capability of withstanding impact loads from a released fan blade. Relatively complex triaxially braided fiber architectures have been found to yield the best performance for the fan cases. To properly work with and design these structures, robust analytical tools are required that can be used in the design process.

A new analytical approach models triaxially braided carbon fiber composite materials within the environment of a transient dynamic finite-element code, specifically the commercially available transient dynamic finite-element code LS-DYNA. The geometry of the braided composites is approximated by a series of parallel laminated composites. The composite is modeled by using shell finite elements. The material property data are computed by examining test data from static tests on braided composites, where optical strain measurement techniques are used to examine the local strain variations within the material. These local strain data from the braided composite tests are used along with a judicious application of composite micromechanics-based methods to compute the stiffness properties of an equivalent unidirectional laminated composite required for the shell elements. The local strain data from the braided composite tests are also applied to back out strength and failure properties of the equivalent unidirectional composite. The properties utilized are geared towards the application of a continuum damage mechanics-based composite constitutive model available within LS-DYNA. The developed model can be applied to conduct impact simulations of structures composed of triaxially braided composites.

The advantage of this technology is that it facilitates the analysis of the deformation and damage response of a triaxially braided polymer matrix composite within the environment of a transient dynamic finite-element code such as LS-DYNA in a manner which accounts for the local physical mechanisms but is still computationally efficient. This methodology is tightly coupled to experimental tests on the braided composite, which ensures that the material properties have physical significance.

Aerospace or automotive companies interested in using triaxially braided composites in their structures, particularly for impact or crash applications, would find the technology useful. By the development of improved design tools, the amount of very expensive impact testing that will need to be performed can be significantly reduced.

Catalyst for Carbon Monoxide Oxidation

This catalyst forms carbon dioxide in a high-powered, pulsed CO_2 laser.

Langley Research Center, Hampton, Virginia

In many applications, it is highly desirable to operate a CO_2 laser in a sealed condition, for in an open system the laser requires a continuous flow of laser gas to remove the dissociation products that occur in the discharge zone of the laser, in order to maintain a stable power output. This adds to the operating cost of the laser, and in airborne or space applications, it also adds to the weight penalty of the laser. In a sealed CO_2 laser, a small amount of CO_2 gas is decomposed in the electrical discharge zone into corresponding quantities of CO and O_2. As the laser continues to operate, the concentration of CO_2 decreases, while the concentrations of CO and O_2 correspondingly increase. The increasing concentration of O_2 reduces laser power, because O_2 scavenges electrons in the electrical discharge, thereby causing arcing in the electric discharge and a loss of the energetic electrons required to boost CO_2 molecules to lasing energy levels. As a result, laser power decreases rapidly.

The primary object of this invention is to provide a catalyst that, by composition of matter alone, contains chemisorbed water within and upon its structure. Such bound moisture renders the catalyst highly active and very long-lived, such that only a small quantity of it needs to be used with a CO_2 laser under ambient operating conditions.

This object is achieved by a catalyst that consists essentially of about 1 to 40 percent by weight of one or more platinum group metals (Pt, Pd, Rh, Ir, Ru,

Os, Pt being preferred); about 1 to 90 percent by weight of one or more oxides of reducible metals having multiple valence states (such as Sn, Ti, Mn, Cu, and Ce, with SnO_2 being preferred); and about 1 to 90 percent by weight of a compound that can bind water to its structure (such as silica gel, calcium chloride, magnesium sulfate, hydrated alumina, and magnesium perchlorate, with silica gel being preferred). Especially beneficial results are obtained when platinum is present in the catalyst composition in an amount of about 5 to 25 (especially 7) percent by weight, SnO_2 is present in an amount of about 30 to 40 (especially 40) percent by weight, and silica gel is present in an amount of 45 to 55 (especially 50) percent by weight.

The composition of this catalyst was suggested by preliminary experiments in which a Pt/SnO_2 catalyst was needed for bound water to enhance its activity. These experimental results suggested that if the water were bound to the surface, this water would enhance and prolong catalyst activity for long time periods. Because the catalyst is to be exposed to a laser gas mixture, and because a CO_2 laser can tolerate only a very small amount of moisture, a hygroscopic support for the catalyst would provide the needed H_2O into the gas. Silica gel is considered to be superior because of its property to chemisorb water on its surface over a wide range of moisture content.

The catalyst may be produced by first preparing a mixture of a commercially available, high-surface-area silica gel and an oxidizing agent. The second step is accomplished by preparing an aqueous mixture of the tin (IV) oxide coated silica gel and a soluble, chloride-free salt of at least one platinum group metal. It is beneficial if the coated silica gel is first deaerated by boiling. The platinum group metal salt is adsorbed onto the high surface area and coats the surface. A chloride-free reducing agent is then added to the aqueous mixture whereby the platinum group metal is deposited onto the tin (IV) oxide coated silica gel. After the platinum group metal has been deposited onto the tin (IV) oxide coated silica gel, the solution is evaporated to dryness, whereby the desired catalyst is obtained.

Titanium Hydroxide — a Volatile Species at High Temperature

John H. Glenn Research Center, Cleveland, Ohio

Titanium hydroxide, $TiO(OH)_2$ (g), has been identified as the primary reaction product of TiO_2 (s) + H_2O (g) at high temperatures (1,200–1,400 °C) through the use of the transpiration technique. This technique is a well-established method used to measure equilibrium pressures at 1 atm. Reactive O_2/H_2O mixtures of gases flow over the sample, and react to form volatile Ti hydroxides. The collected reaction gas condensate is analyzed to determine the vapor and dissociation pressures. From the amount of condensate and its relation to the partial pressures of the reactive gases, the identity of the volatile hydroxide can be determined. From the relation of product pressure to temperature, thermodynamic enthalpy and entropy of formation can be calculated.

The reaction of the identified titanium hydroxide is useful to understanding the volatility of titanium-containing materials for high-temperature conditions that contain water vapor (i.e., combustion from hydrocarbon fuels, etc.). The identity of this molecule and thermodynamic data on this molecule contribute to the high-temperature materials database that would directly impact future selection of refractory oxide materials for use in combustion environments. This will also aid in furthering the understanding of oxide stability with high-temperature water vapor.

Selective Functionalization of Carbon Nanotubes: Part II
Different species are deposited at different distances.

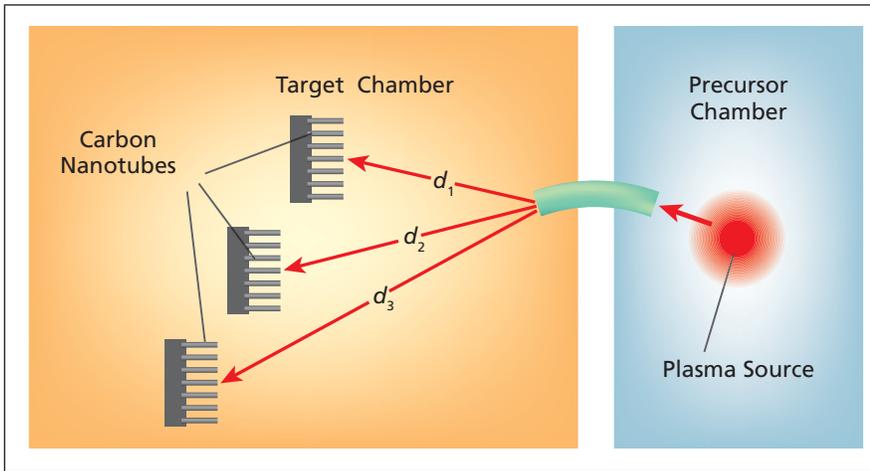*Ames Research Center, Moffett Field, California*

An alternative method of low-temperature plasma functionalization of carbon nanotubes provides for the simultaneous attachment of molecular groups of multiple (typically two or three) different species or different mixtures of species to carbon nanotubes at different locations within the same apparatus. This method is based on similar principles, and involves the use of mostly the same basic apparatus, as those of the methods described in "Low-Temperature Plasma Functionalization of Carbon Nanotubes" (ARC-14661-1), *NASA Tech Briefs*, Vol. 28, No. 5 (May 2004), page 45.

The figure schematically depicts the basic apparatus used in the aforementioned method, with emphasis on features that distinguish the present alternative method from the other. In this method, one exploits the fact that the composition of the deposition plasma changes as the plasma flows from its source in the precursor chamber toward the nanotubes in the target chamber. As a result, carbon nanotubes mounted in the target chamber at different flow distances (d_1, d_2, d_3 . . .) from the precursor chamber become functionalized with different species or different mixtures of species.

In one series of experiments to demonstrate this method, N_2 was used as the precursor gas. After the functionalization process, the carbon nanotubes from three different positions in the

Nanotubes at Different Distances from the precursor chamber are exposed to different plasma compositions and, hence, become differently functionalized.

target chamber were examined by Fourier-transform infrared spectroscopy to identify the molecular groups that had become attached. On carbon nanotubes from $d_1 = 1$ cm, the attached molecular groups were found to be predominantly $C=N$ and $C\equiv N$. On carbon nanotubes from $d_2 = 2.5$ cm, the attached molecular groups were found to be predominantly $C-(NH)_2$ and/or $C=NH_2$. (The H_2 was believed to originate as residual hydrogen present in the nanotubes.) On carbon nanotubes from $d_3 = 7$ cm no functionalization could be detected — perhaps, it was conjectured, because this distance is downstream of the plasma source, all of the free ions and free radicals of the plasma had recombined into molecules.

Steerable Hopping Six-Legged Robot

Motions of spring legs are coordinated in both launch and landing.
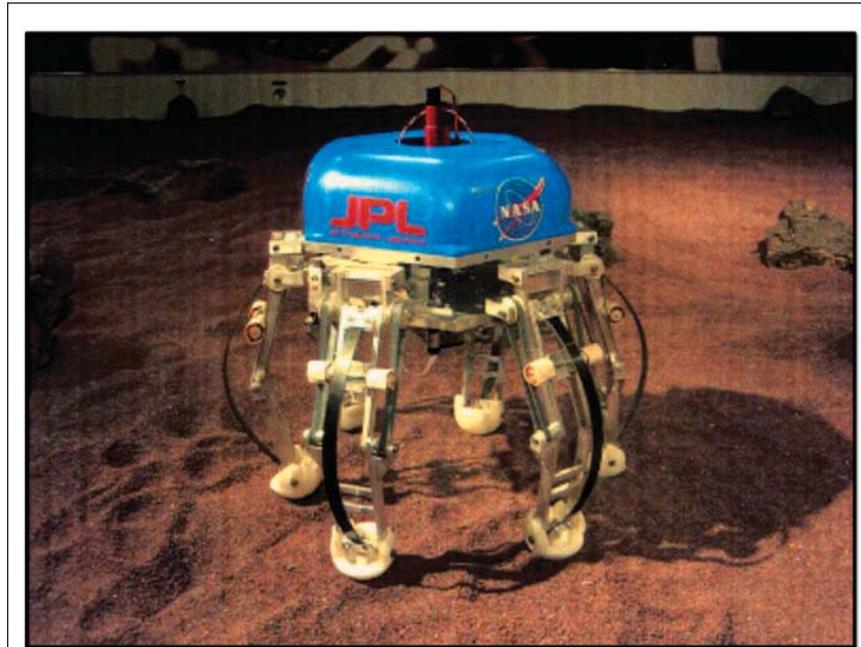
NASA's Jet Propulsion Laboratory, Pasadena, California

The figure depicts selected aspects of a six-legged robot that moves by hopping and that can be steered in the sense that it can be launched into a hop in a controllable direction. This is a prototype of hopping robots being developed for use in scientific exploration of rough terrain on remote planets that have surface gravitation less than that of Earth. Hopping robots could also be used on Earth, albeit at diminished hopping distances associated with the greater Earth gravitation.
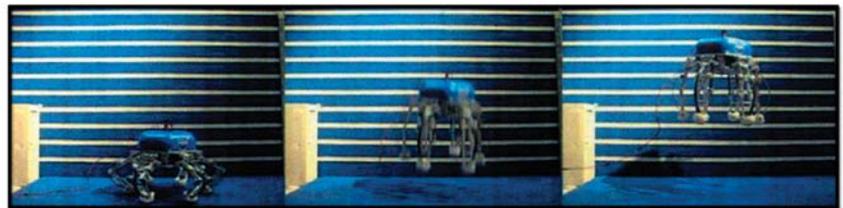
The upper end of each leg is connected through two universal joints to an upper and a lower hexagonal frame, such that the tilt of the leg depends on the relative position of the two frames. Two non-backdriveable worm-gear motor drives are used to control the relative position of the two frames along two axes 120° apart, thereby controlling the common tilt of all six legs and thereby, further, controlling the direction of hopping.

Each leg includes an upper and a lower aluminum frame segment with a joint between them. A fiberglass spring, connected via hinges to both segments, is used to store hopping energy prior to launch into a hop and to cushion the landing at the end of the hop. A cable for loading the spring is run into each leg through the center of the universal joints and then down along the center lines of the segments to the lower end of the leg. A central spool actuated by a motor with a harmonic drive and an electromagnetic clutch winds in all six cables to compress all six springs (thereby also flexing all six legs) simultaneously. To ensure that all the legs push off and land in the same direction, timing-belt pulley drives are attached to the leg segments, restricting the flexing and extension of all six legs to a common linear motion.

In preparation for a hop, the spool can be driven to load the spring legs by an amount corresponding to a desired hop distance within range. The amount of compression can be computed from the reading of a shaft-angle encoder that indicates the amount by which the spool has been turned. When the robot is ready to hop, the electromagnetic clutch disengages the motor from the spool, thus releasing the cable restraints on the springs and allowing the springs to extend all six legs simultaneously.

Hopping Robot

Hopping Sequence

Tilting Legs For Steering

Six Spring Legs are driven in coordinated flexion and extension to effect hopping motion. The legs can be tilted to control the direction of hopping. A gyroscope helps to prevent tumbling during launch, flight, and landing.

When the robot lands, the springs in the legs are compressed as they absorb much of the impact. As the legs retract, a constant-force spring motor attached to the spool winds in the leg cables to keep them taught. A unidirectional clutch in line with the spool and the spool motor drive allows the spool to quickly overrun the motor drive when winding up the cable, but locks when the springs in the legs try to pull the cable back out. This action prevents bouncing after landing and provides for storage of energy for reuse on the next hop. A motor-driven gyroscope mounted on the lower hexagonal frame helps to prevent tumbling of the robot during hopping and was tested through computer simulation.

This work was done by Paulo Younse and Hrand Aghazarian of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-45062

⚙ Launchable and Retrievable Tetherobot

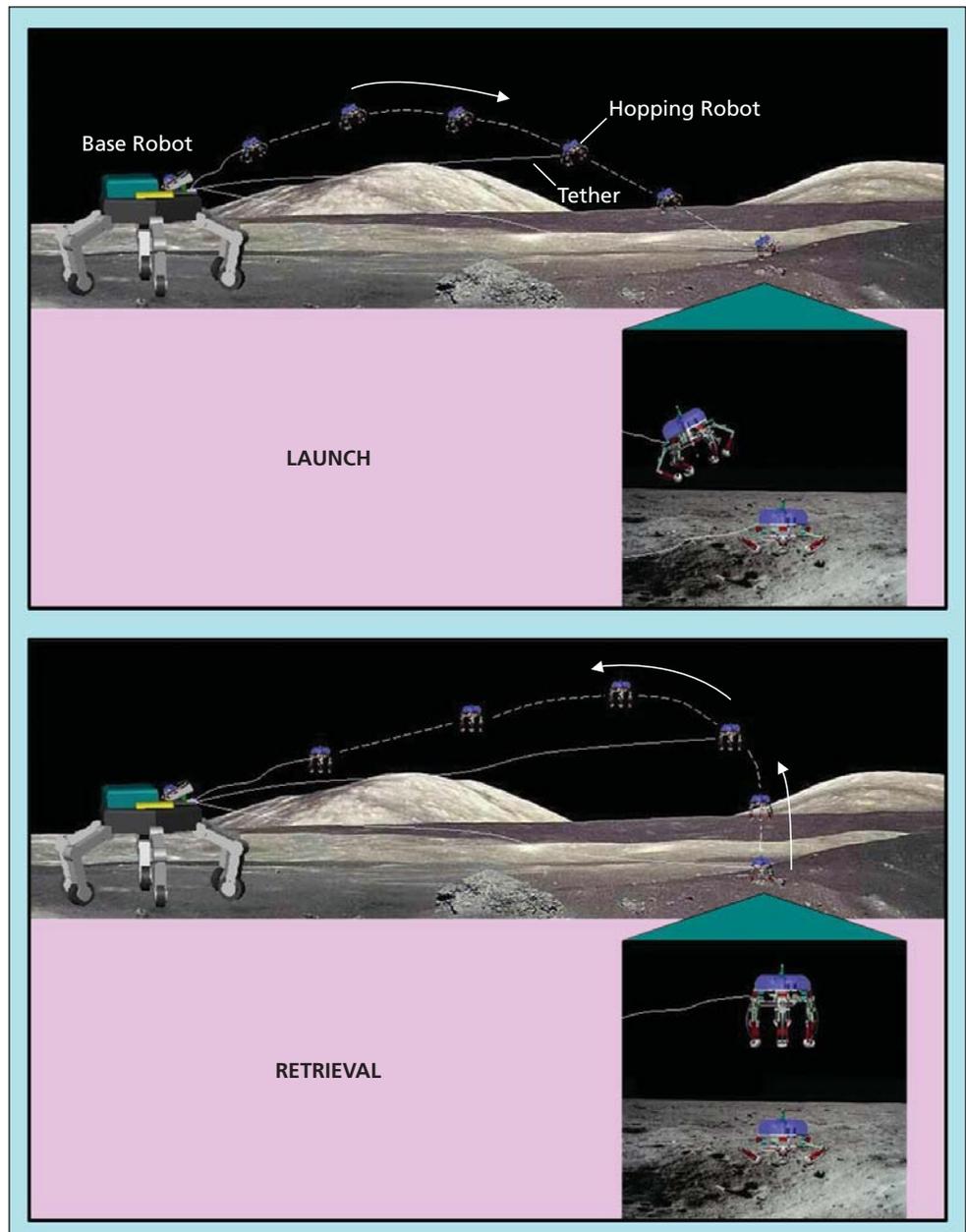## The reach of an exploratory robot on rough terrain would be extended.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed robotic system for scientific exploration of rough terrain would include a stationary or infrequently moving larger base robot, to which would be tethered a smaller hopping robot of the type described in the immediately preceding article. The two-robot design would extend the reach of the base robot, making it possible to explore nearby locations that might otherwise be inaccessible or too hazardous for the base robot.

The system would include a launching mechanism and a motor-driven reel on the larger robot. The outer end of the tether would be attached to the smaller robot; the inner end of the tether would be attached to the reel.

The figure depicts the launching and retrieval process. The launching mechanism would aim and throw the smaller robot toward a target location, and the tether would be paid out from the reel as the hopping robot flew toward the target. Upon completion of exploratory activity at the target location, the smaller robot would be made to hop and, in a coordinated motion, the tether would be wound onto the reel to pull the smaller robot back to the larger one.

At the time of reporting the information for this article, the launching and retrieval processes had been studied by computational simulations for various

The **Smaller Tethered Hopping Robot** would be thrown toward a target by a launching mechanism on the larger robot. Later, the hopping robot would be retrieved by reeling in the tether during a hop.

launching angles, target distances, hopping heights and angles, and tether-reel-in rates. A prototype hopping robot and a reel had been built.

Work on the launching mechanism and on control subsystems for the hopping robot and the reel remained to be done.

✿ Hybrid Heat Exchangers

John H. Glenn Research Center, Cleveland, Ohio

A hybrid light-weight heat exchanger concept has been developed that uses high-conductivity carbon-carbon (C–C) composites as the heat-transfer fins and uses conventional high-temperature metals, such as Inconel, nickel, and titanium as the parting sheets to meet leakage and structural requirements.

In order to maximize thermal conductivity, the majority of carbon fiber is aligned in the fin direction resulting in 300 W/m·K or higher conductivity in the fin directions. As a result of this fiber orientation, the coefficient of thermal expansion (CTE) of the C–C composite in both non-fiber directions matches well with the CTE of various high-temperature metal alloys. This allows the joining of fins and parting sheets by using high-temperature braze alloys.

✿ Orbital Winch for High-Strength, Space-Survivable Tethers

Marshall Space Flight Center, Alabama

An Orbital Winch mechanism enables high-load, multi-line tethers to be deployed and retracted without rotating the spool on which the tether is wound. To minimize damage to the tether and the wound package during retraction or deployment under load, it can incorporate a Tension Management Module that reduces the infeed tension by a factor of 15 through the use of a powered capstan with guide rollers. This design eliminates the need for rotating high-voltage electrical connections in tether systems that use propellantless electro-dynamic propulsion. It can also eliminate the need for rotating optical connections in applications where the tether contains optical fibers.

This winch design was developed to deploy a 15-km-long, 15-kg high-strength Hoytether structure incorporating conductive wires as part of the MXER-1 demonstration mission concept. Two slewing rings that orbit around the tether spool, combined with translation of one of the slewing rings back and forth along the spool axis to traverse the wind point, enables the winch to wind the tether. Variations of the traverse motion of the slewing ring can accomplish level winds and conical pirn winds. By removing the non-traversing slewing ring, and adding an actuated guide arm, the winch can manage rapid, low-drag deployment of a tether off the end of a pirn-wound spool, followed by controlled retraction and rewinding, in a manner very similar to a spin-casting reel. The winch requires at least two motor driver controller units to coordinate the action of two stepper motors to accomplish tether deployment or retraction.

Parameterized Linear Longitudinal Airship Model

NASA's Jet Propulsion Laboratory, Pasadena, California

A parameterized linear mathematical model of the longitudinal dynamics of an airship is undergoing development. This model is intended to be used in designing control systems for future airships that would operate in the atmospheres of Earth and remote planets.

Heretofore, the development of linearized models of the longitudinal dynamics of airships has been costly in that it has been necessary to perform extensive flight testing and to use system-identification techniques to construct models that fit the flight-test data. The present model is a generic one that can be relatively easily specialized to approximate the dynamics of specific airships at specific operating points, without need for further system identification, and with significantly less flight testing.

The approach taken in the present development is to merge the linearized dynamical equations of an airship with techniques for estimation of aircraft stability derivatives, and to thereby make it possible to construct a linearized dynamical model of the longitudinal dynamics of a specific airship from geometric and aerodynamic data pertaining to that airship. (It is also planned to develop a model of the lateral dynamics by use of the same methods.) All of the aerodynamic data needed to construct the model of a specific airship can be obtained from wind-tunnel testing and computational fluid dynamics.

This work was done by Eric Kulczycki, Alberto Elfes, David Bayard, Marco Quadrelli, and Joseph Johnson of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-45346

Physics of Life: A Model for Non-Newtonian Properties of Living Systems
New analytical tools focus on the geometry and kinematics of behavior of living things.

NASA's Jet Propulsion Laboratory, Pasadena, California

This innovation proposes the reconciliation of the evolution of life with the second law of thermodynamics via the introduction of the First Principle for modeling behavior of living systems. The structure of the model is quantum-inspired: it acquires the topology of the Madelung equation in which the quantum potential is replaced with the information potential. As a result, the model captures the most fundamental property of life: the progressive evolution; i.e. the ability to evolve from disorder to order without any external interference.

The mathematical structure of the model can be obtained from the Newtonian equations of motion (representing the motor dynamics) coupled with the corresponding Liouville equation (representing the mental dynamics) via information forces. All these specific non-Newtonian properties equip the model with the levels of complexity that matches the complexity of life, and that makes the model applicable for description of behaviors of ecological, social, and economical systems.

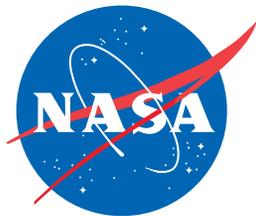Rather than addressing the six aspects of life (organization, metabolism, growth, adaptation, response to stimuli, and reproduction), this work focuses only on "biosignature"; i.e. the mechanical invariants of life, and in particular, the geometry and kinematics of behavior of living things. Living things obey the First Principles of Newtonian mechanics. One main objective of this model is to extend the First Principles of classical physics to include phenomenological behavior on living systems; to develop a new mathematical formalism within the framework of classical dynamics that would allow one to capture the specific properties of natural or artificial living systems such as formation of the collective mind based upon abstract images of the selves and non-selves; exploitation of this collective mind for communications and predictions of future expected characteristics of evolution; and for making decisions and implementing the corresponding corrections if the expected scenario is different from the originally planned one. This approach postulates that even a primitive living species possesses additional, non-Newtonian properties that are not included in the laws of Newtonian or statistical mechanics. These properties follow from a privileged ability of living systems to possess a self-image (a concept introduced in psychology) and to interact with it.

The proposed mathematical system is based on the coupling of the classical dynamical system representing the motor dynamics with the corresponding Liouville equation describing the evolution of initial uncertainties in terms of the probability density and representing the mental dynamics. The coupling is implemented by the information-based supervising forces that can be associated with self-awareness. These forces fundamentally change the pattern of the probability evolution, and therefore, lead to a major departure of the behavior of living systems from the patterns of both Newtonian and statistical mechanics.

This innovation is meant to capture the signature of life based only on observable behavior, not on any biochemistry. This will not prevent the use of this model for developing artificial living systems, as well as for studying some general properties of behavior of natural, living systems.

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